APPENDIX B: AQUIFER SURVEILLANCE METHODOLOGY

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B.1 Introduction

This appendix provides an overview of QGCs simplified groundwater level trend analysis technique and examples of application of the approach to identify impact to the aquifers.

B.1.1 Routine Aquifer Surveillance – Hydrograph Analysis

QGC have previously presented a trend analysis methodology in the 2013 Stage 3 WMMP. Since development of that document QGC's understanding of the Surat Basin groundwater system has improved through the regular analysis and interpretation of groundwater level and pressure monitoring datasets. The improved understanding of the groundwater system has enabled QGC to refine its approach to analysing groundwater trends, as part of routine aquifer surveillance activities. The new trend analysis approach includes understanding of the physical characteristics of the groundwater system and incorporates an understanding of climatic variation, third party groundwater use, and likely responses due to CSG production on both a local and more regional scale within the groundwater system. The new approach focuses on identifying causation of trends locally and more regionally so that any change to the system, potentially caused by CSG production can be rapidly identified and then quantified.

The key assumptions of the new approach are as follows: that water levels within a bore will fluctuate in response to natural and/or anthropogenic stresses exerted on the groundwater system. That is:

- The addition of pressure to the system will result in rising water levels;
- The removal of pressure from the system will result in falling water levels;
- Changes in rate of decline or rate of rise do not always indicate an additional stress has been applied to a system. They can simply be an indication of the geometry of the aquifer, demonstrating where a boundary has been reached.
- Datasets displaying absolutely no variation in water level are not expected and should be considered potentially erroneous; and
- While data from a single bore is useful, consideration of data from multiple bores are need to track responses across the aquifer and development of any cones of depression.

A summary of processes that can affect groundwater levels in local, medium and long temporal scales is contained in Table B.1 - Summary of processes affecting groundwater levels

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Table B.1 - Summary of processes affecting groundwater levels

Temporal Scale	Processes
Short	Air pressure fluctuations (barometric)
	Earth tides, due to the sun and moon's gravitational effects
Medium	Seasonal recharge events
	Local groundwater pumping
	Loading of confined aquifers due to recharge to overlying unconfined aquifers or from flooding (this can be medium or long term, depending on the nature of the influence)
Long	Regional groundwater pumping for water supply purposes (including stock and domestic pumping and free flowing bores, irrigation use, other users)
	Long term climatic patterns affecting recharge (drought, wet conditions)
	Land use changes affecting recharge (cropping or land-clearing changes)
	Loading of confined aquifers due to recharge to overlying unconfined aquifers or from flooding (this can be medium or long term, depending on the nature of the influence)
	Regional scale aquifer rehabilitation programs that restore groundwater pressures by capping and decommissioning old and free flowing bores
	Propagation of pressure reduction due to CSG pumping from Coal Measures strata.

A trend in groundwater level can be defined as a rate of change (gradient of line of best fit) and the amplitude of typical fluctuations (oscillations around the line of best fit).

As such, the refined Routine Trend Analysis approach consists of the following steps:

- Compile background datasets: details on bore construction and history, aquifer type and properties, climatic datasets, CSG gas and water production, details of surrounding groundwater users for bore.
- Graph groundwater level (in mAHD) within the bore over time for duration of monitoring.
- Undertake visual QAQC of hydrograph (including check against manual dips) to confirm data is error free and an accurate representation of bore pressure;
- Determine overall trend of graph (rising, falling, fluctuating or flat) and trend of most recent 3 months.
- Mark up graph to illustrate any observable inflection points which indicate changes to the groundwater system including rate of change.
- If bore is declining, determine if it is within close proximity to current or historical CSG production.
- Undertake desktop investigation into potential causation of decline and inflection points for bores within close proximity to CSG production.
- Test assumptions of potential causation (eg via analytical modelling).
- Report on findings.

B.1.2 Hydrogeologically Relevant Datasets

Attributing causation to fluctuation in groundwater levels requires access to large quantities of supporting hydrogeological information. Figure B.1 contains a table of information types that are accessed during QGC Aquifer Surveillance activities and in particular, Routine Hydrograph interpretation. The data sets can be categorised into:

- Bore construction details
- Groundwater level monitoring data
- Environmental/climatic monitoring data;
- Other groundwater users
- Gas and Water Production data
- Hydrogeological conceptualisation
- UWIR modelling outputs
- Qualitative data analysis
- Quantitative data analysis.

This approach will be further refined over the coming 3 years as more information is obtained and interpreted.

Figure B.1 - Summary of processes affecting groundwater levels

Details
Bore Details
Bore ID
Latitude
Longitude
Development area
Total Depth
Screened Interval (m) (to include entire thickness of possible open hole
Screened Interval (lithology)
Screened Interval (formation)
Bore construction diagram sighted?
Bore construction adequate for pressure/level monitoring?
Bore baseline level
Bore trigger level
GW Level Montitoring Data
Start of gw level monitoring
End of gw level monitoring
Duration of gw level records
Frequency of records (eg hourly)
Number of records
Primary measurement technique (eg manual dip, transducer etc)
Secondary measurement verification technique (eg manual dip)
Downhole temperature measurements available at gauge?
Graph of groundwater level fluctuation over time? Must be at suitable scale to identify threshold excedances
Environmental Monitoring Data
Barometric pressure monitoring station
Graph of barometric pressure and gw pressure in KpA plotted over time?
Weather/rainfall monitoring station
Graph of rainfall residual mass curve plotted over time?
Other Groundwater Users
Number of Third Party Bores within 2 km radius (all aquifers)
Distance to nearest groundwater extraction bore
Distance to nearest groundwater extraction bore within same aquifer
Approximate extraction rate of nearest bore (if unknown, state purpose of bore)
Gas Production
Map illustrating bore location in relation to production wells within 2km radius and mapped geological stuctures.
Number of gas production bores within 2km radius
Horizontal distance to nearest operational gas production bore (m)
Vertical distance between monitored interval and top of open hole within nearest CSG extraction bore
Adequate aquitard layer >5m thickness present between production zone and screened interval?
Water production volumes over time from production wells within
up, down or across dip from bore?
horizontal distance from nearest other proponent operating CSG bore
up, down or across dip from bore?
UWIR
Within IAA?
Within LAA?
OGIA predicted maximum likely drawdown (m)

Summary of processes affecting groundwater levels - continued

Details
Conceptualisation
Map illustrating bore location in relation to other groundwater users, weather station, rivers and topography?
Representative cross section available illustrating geology, faults, monitoring bore, production zone and other users, including their screened intervals?
Estimate of Kh of screened interval?
Estimate of Kv of screened interval?
Estimate of S for screened interval?
Primary porosity or secondary porosity?
Estimate of Porosity?
Assumed aquifer thickness (b)?
Hydraulic parameters based on what? (source)
2D analytical model exists for bore?
Proximity to recharge zone? (distance)
Qualitative Data Analysis
Visual gw trend orientation (flat, up, down) of entire dataset
Multiple trends, or single trend?
Overall gradient (m/yr)
Visual gw trend orientation (flat, up, down) of last 3 months
Multiple trends, or single trend?
magnitude of gw level fluctuation (m) (ie amplitude of fluctuations)
Overall 3 month gradient (m/yr)
Visible inflection points within trend?
Does bore hydrograph correlate to any other hydrographs in region, regardless of aquifer screened?
Is there confidence in the accuracy of data (ie. is trend real)?
Quantitative Data Analysis
Magnitude of gw level fluctuation (kPa)
Magnitude of baro pressure fluctuation (kPa)
Sufficient data to create map of pre-CSG potentiometric surface and current potentiometric surface within aquifer for surrounding 50 km?
Map illustrating groundwater drawdown across region since onset of monitoring?
Trend meets minimum data set duration required (Y/N)
Meets minimum number of data points required for legitimate assessment (Y?N)
Actual vertical distance between monitored interval and top of open hole within nearest CSG extraction bore
Suspect catastrophic failure of bore?

B.1.3 Worked Example – Routine Hydrograph Analyses

Two examples of routine hydrograph analyses are provided below. Table B.2 and Table B.3 illustrate a hydrograph of groundwater levels within the Coochiemudlow GW1 monitoring bore and related Routine Hydrograph Analysis summary. This bore is screened within the Hutton Sandstone and is located outside of operational CSG production areas. Trends within this bore are reflective of baseline conditions within the aquifer.

Figure B.2 - Graph illustrating declining groundwater levels (baseline conditions) within Coochiemudlo GW1

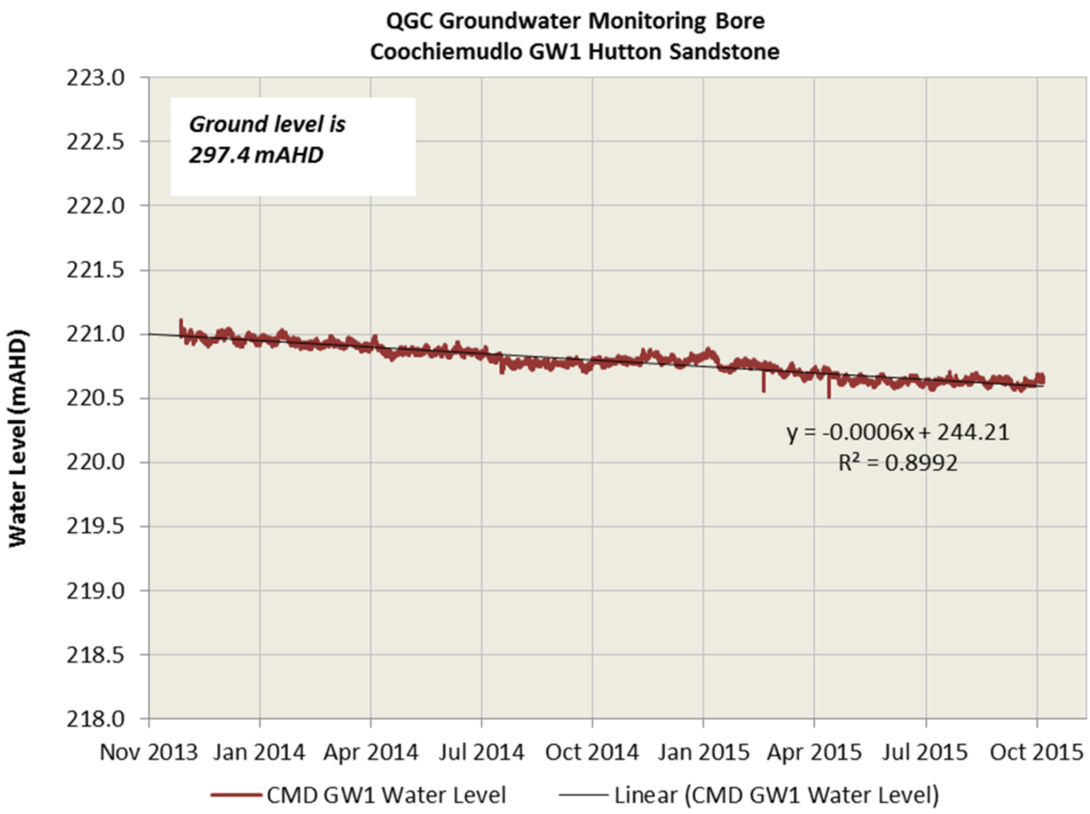

Table B.2 - Summary of Routine Hydrograph Analysis – Coochimudlo GW1

Item	***Details***
Bore ID	*Coochiemudlo GW1*
Screened Aquifer	*Hutton Sandstone*
Duration of monitoring	*Dec 2013 to Oct 2015*
Overall groundwater trend	*Declining*
Within operational CSG field?	*No*
Baseline Trend	*y=0.0006x+244.21*
Amplitude of fluctuation	*± 0.15m*
R^2	*0.8992*
Current Trend	*Consistent with baseline*
Fluctuation	*Consistent with baseline*
Issue Present?	***No***
Explanation/Causation	*Decline due to third party groundwater extraction*
QGC CSG impact evident?	*No*

Conversely, Figure B.2 and Figure B.3 illustrate a hydrograph of groundwater levels within Kenya East GW4 monitoring bore and related Routine Hydrograph Analysis Summary. Kenya East GW4 is located within the operating Kenya East production field (not within the Study Area) and a thorough investigation into declining water levels within the monitoring bore has identified the lower interval of the Springbok Sandstone and producing zones within the Walloon Subgroup are in direction hydraulic connection due to the presence of faulting. The hydraulic connection is a localised feature, and similar impacts are not observed in other Springbok monitoring bores at this location.

Figure B.3 - Graph illustrating trend analysis within Kenya East GW4. Trend analysis clearly identified a potential impact that required immediate investigation.

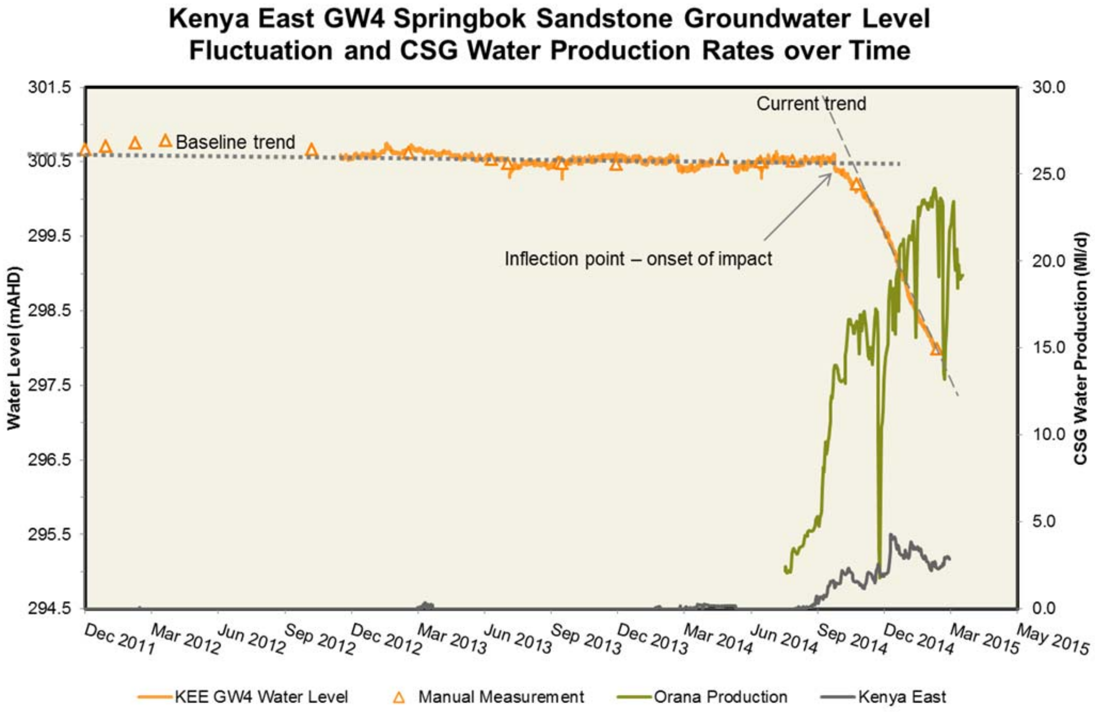

Table B.3 - Summary of Routine Hydrograph Analysis – Kenya East GW4

Item	***Details***
Bore ID	*Kenya East GW4*
Screened Aquifer	*Springbok Sandstone*
Duration of monitoring	*Dec 2011 to Mar 2015*
Overall groundwater trend	*Declining*
Within operational CSG field?	*Yes*
Baseline GW Level Trend	*<0.1m/year*
Amplitude of fluctuation	*± 0.1m*
Current Trend	*~6m/year*
Current amplitude of fluctuation	*± 0.1m*
Issue Present?	*Yes*
Explanation/Causation	*Bore proven to be in direct hydraulic connection with production zone due to presence of faulting.*
QGC CSG impact evident?	*Yes*

Outcomes of the Routine Trend Analyses are tabulated and stored for future reference. Due to the infancy of monitoring within some bores, their baseline trend is not yet clear. QGC tracks trends within each bore via a traffic light system, which visually highlights the potential impact status of the bore. QGC's Impact Status definitions are described in Table B.4

Table B.5 illustrates an example Routine Trend Analysis Record Sheet for bores within the Study Area and immediate surrounds. Bores are assessed on a three monthly basis using this approach. Follow up actions for each bore (eg increase monitoring frequency, check field equipment, undertake further bore assessment etc) are assigned based on the outcomes of the quarterly Routine Trend Analysis process.

Table B.4 - Key of Impact Status for Aquifer Surveillance

Impact Status	Impact Summary	Impact Description	Action Required
	Nil	Hydrographs stable or responding to evironmental fluctuations. No QGC CSG impact suspected.	Continue routine monitoring
	Watch	Hydrographs displaying fluctuations inconsistent with environmental fluctuations. Potentially affected by QGC CSG, QGC construction water supply or third party activities.	Increase to monthly hydrograph review and commence compiling information for bore assessment.
	Investigate	Hydrograph displaying clear groundwater pressure impact requiring immediate investigation. Likely to be due to QGC CSG activities but possibly third party activities.	**Investigate immediately**. Increase to monthly hydrograph review. Initiate relevant response plan as per WMMP. Regular close inspection and analysis of data.
	Proven QGC CSG Impact	Bore investigated previously - groundwater pressure impact due to QGC CSG water extraction.	Continued regular close inspection and analysis of data required. Further investigations as required.
	Proven 3rd Party Impact	Bore investigated previously - groundwater pressure impact due to third party activities.	Continued regular close inspection and analysis of data required. Further investigations as required.
	Insufficient data	Insufficient data to determine trend.	Investigate lack of data and bring online ASAP

Table B.5 - Example of Routine Trend Analysis Record Sheet for bores within the Study Area and immediate surrounds.

Block	Bore	Formation	Groundwater Pressure Trer	Magnitude of Change	Impact Statu	Impact Cause	Action Status	Comment
Charlie	GW1	Hutton	→				Nil	Spring monitoring bore.
Charlie	GW2	Precipice	↗	2.97m rise since Dec 2014		other	Watch	Spring monitoring bore. Suspect pressure increase due to third party actions.
Charlotte	GW1	Hutton	↘	3.5 m decline since Sep 2013		other	Proven 3rd Party Impact	Spring monitoring bore. Increase in rate of decline since April 2015. Outside production area - decline due to local third party irrigation usage. Gauge failed in June 2015 and replaced in November 2015. Download gauge ASAP.
Charlotte	GW2	Precipice	↗	1.4m rise since Jul 2015.		other	Watch	Spring monitoring bore. Recovering following workover. Rate of rise = 3.75m/year in 2015. Rise possibly due to CSG activities (injection) or reduction of 3rd party groundwater use.
Coochiemudlo	GW1	Hutton	↘	0.5 m decline since Nov 2013.		other	Watch	Spring monitoring bore. Outside production area - suspect decline due to local third party usage and regional discharge.
Coochiemudlo	GW2	Precipice	→				Nil	Spring monitoring bore. Natural fluctuation.
Peebs	GW17	Gubberamunda	→				Nil	
Peebs	GW18	Springbok	↗	1.36m rise since Aug 2014			Nil	Outside production area.

B.1.4 Frequency of Aquifer Surveillance – Hydrograph Reviews

QGC undertake regular review of groundwater level hydrographs. Data is reviewed on a fortnightly, monthly and quarterly basis as detailed in Table B.6. This ensures that any potential impact to the groundwater system will be identified, investigated and reported in a timely manner.

Table B.6 - Aquifer surveillance – frequency of hydrograph review

Activity	Frequency
Confirm that telemetry system is functioning and data is being received in the office	Fortnightly
Sight all hydrographs and confirm there are no major anomalies or trends developing over time	Monthly
Review all hydrographs and document trends in internal memo.	Quarterly
Undertake trend analysis and Notify DoE of any exceedances as per Baseline Identification and Aquifer Surveillance Procedures (QCLNG-BE99-WAT-RPT-000010)	Annually
Provide data to OGIA and publish hydrographs to website	Bi-annually